FISHERY RESEARCH

ASSESSMENT OF NATIVE SALMONIDS ABOVE HELLS CANYON DAM, IDAHO

ANNUAL PROGRESS REPORT
July 1, 2004—June 30, 2005

Prepared by:

Kevin A. Meyer, Principal Fisheries Research Biologist
James A. Lamansky, Jr., Senior Fisheries Technician

IDFG Report Number 05-41
August 2005

Assessment of Native Salmonids Above Hells Canyon Dam, Idaho

Project Progress Report

2004 Annual Report

By

Kevin A. Meyer
James A. Lamansky, Jr.

Idaho Department of Fish and Game
600 South Walnut Street
P.O. Box 25
Boise, ID 83707

To

U.S. Department of Energy
Bonneville Power Administration
Division of Fish and Wildlife
P.O. Box 3621
Portland, OR 97283-3621

Project Number 1998-002-00
Contract Number 00022947

IDFG Report Number 05-41
August 2005

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

PART #1: AN EVALUATION OF A BROOK TROUT REMOVAL PROJECT IN A SMALL ROCKY MOUNTAIN STREAM

ABSTRACT

In the western United States, exotic brook trout *Salvelinus fontinalis* frequently have a deleterious effect on native salmonids, and biologists often attempt to remove brook trout in streams using electrofishing. Although the success of electrofishing removal projects typically is low, few studies have assessed the underlying mechanisms of failure, especially in terms of compensatory responses. We evaluated the effectiveness of a three-year removal project in reducing brook trout and enhancing native salmonids in 7.8 km of an Idaho stream and looked for brook trout compensatory responses such as decreased natural mortality, increased growth, increased fecundity at length, or earlier maturation. Due to underestimates of the distribution of brook trout in the first year and personnel shortages in the third year, the multiagency watershed advisory group that performed the project fully treated the stream (i.e. multipass removals over the entire stream) in only one year. In 1998, 1999, and 2000, a total of 1,401, 1,241, and 890 brook trout were removed, respectively. For 1999 and 2000, an estimated 88 and 79% of the total number of brook trout in the stream were removed. For the section of stream that was treated in all years, the abundance of age-1 and older brook trout decreased by 85% from 1998 to 2003. In the same area, the abundance of age-0 brook trout decreased 86% from 1998 to 1999 but by 2003 had rebounded to near the original abundance. Abundance of native redband trout *Oncorhynchus mykiss* decreased for age-1 and older fish but did not change significantly for age-0 fish. Despite high rates of removal, total annual survival rate for brook trout increased from 0.08 ± 0.02 in 1998 to 0.20 ± 0.04 in 1999 and 0.21 ± 0.04 in 2000. Growth of age-0 brook trout was significantly higher in 2000 (the year after their abundance was lowest) compared to other years, and growth of age-1 and age-2 brook trout was significantly lower following the initial removal years but recovered by 2003. Few other brook trout demographic parameters changed appreciably over the course of the project. Electrofishing removals required 210 person-days of effort. Despite experiencing slight changes in abundance, growth, and survival, brook trout in Pikes Fork appeared little affected by three years of intensive removal efforts, most likely because mortality within the population was high prior to initiation of the project such that the removal efforts merely replaced natural mortality with exploitation.

Authors:

Kevin A. Meyer
Principal Fisheries Research Biologist

James A. Lamansky, Jr.
Senior Fisheries Technician

INTRODUCTION

Introduced fish species that establish self-sustaining populations are a primary threat to the long-term persistence of native fish fauna (Moyle 1986; Allan and Flecker 1993; Rahel 2000). A classic example is the brook trout *Salvelinus fontinalis*, which has been introduced since the late 1800s to diversify or supplement sportfishing opportunities. Brook trout have become widely established in every state in the western USA (Fuller et al. 1999), usually to the detriment of native salmonids (Krueger and May 1991; Young 1995; Levin et al. 2002; see review in Dunham et al. 2002). The ability of brook trout to repeatedly outcompete and displace native salmonids has become increasingly evident, but the mechanisms for their success remain relatively unknown and unstudied (Griffith 1988; Fausch 1988, 1989; but see Peterson et al. 2004a).

Because of these detrimental effects, biologists have focused effort on reducing or removing brook trout for conservation and restoration of native salmonids. The most common methods for removing nonnative stream-dwelling salmonids have been electrofishing (e.g., Moore et al. 1983; Thompson and Rahel 1996; Kulp and Moore 2000; Shepard et al. 2002) and toxicants (e.g., Phinney 1975; Gresswell 1991), although selective angling (Larson et al. 1986; Paul et al. 2003) and trapping (Young et al. 2003) have been used as well. In general, removal projects have met with little success. Indeed, Meronek et al. (1996) reviewed 250 fish control projects and found that the goals of reducing or eliminating undesirable fish species were met in less than 50% of the projects they reviewed. Nevertheless, the lack of alternatives to removal and the perceived need to constrain exotics such as brook trout compels many biologists to continue implementing fish control projects (Finlayson 2005).

Because toxicants such as rotenone and antimycin kill nontarget species, electrofishing is often viewed by many biologists as a more desirable alternative for fish removal. However, electrofishing has many of its own shortcomings. First, complete removal is difficult. Thompson and Rahel (1996) effectively removed 73–100% of age-0 and 59-100% of age-1+ brook trout from three streams in Wyoming but did not completely eradicate brook trout from any stream. Others have eradicated nonnative trout but at tremendous cost for very small (e.g., 0.8–3.0 km) sections of stream (Kulp and Moore 2000; Shepard et al. 2002). Another shortcoming is that mobile species such as brook trout recolonize rapidly unless a barrier between treated and untreated reaches is established. Phinney (1975) found that a stream section treated with rotenone was repopulated by brook trout from upstream within one year. Similarly, Peterson et al. (2004a) found that immigration replaced 40–100% of the adult brook trout that were removed the previous year.

Even when barriers are established, suppressed populations of brook trout often recover quickly because they mature earlier than most other salmonids. For example, in an attempt to evaluate growth response, Cooper et al. (1962) treated a stream with rotenone to severely reduce (not eliminate) the number of brook trout. There was no change in growth rate. Instead, brook trout abundance quickly recovered and within two years was no different from before the treatment, with almost all fish being age-0 or age-1. Furthermore, any remaining or recolonizing brook trout in a treated section may undergo a compensatory response once the fish population has been reduced (McFadden 1961, 1976), negating some or all of the effects of the removal. The term ‘compensation’ (taken from McFadden 1977) refers to the propensity of populations to exhibit reduced death rates or increased birth rates as a population declines (it can also be the opposite). The effect is to (1) stabilize the population before it is extirpated or (2) restore the population toward its original condition (McFadden 1977). In the simplest terms, such changes often stem from a reduction in competition for food or space. Previous studies have indicated that brook trout may compensate for increased exploitation through a variety of methods, including decreased natural mortality (McFadden 1961), increased growth and recruitment (Donald and Alger 1989), and increased age-specific fecundity (Jensen 1971). Because these and other mechanisms are not mutually exclusive and may interact at a variety of life-history stages, only a few may be statistically verifiable at any given period of observation (McFadden 1977).

In this paper, we describe an electrofishing removal project that was initiated and conducted by a local watershed advisory group (WAG) in southwestern Idaho. The goal of their project was to eliminate or suppress brook trout in a small stream to protect native salmonids (redband trout *Oncorhynchus mykiss* and bull trout *S. confluentus*) in the stream. We (the present authors) were asked to carefully evaluate the costs and success of the project as there was strong interest in conducting similar removal projects by other biologists in southwestern Idaho. Because bull trout were nearly extirpated by the time this project was initiated, we monitored population changes for brook trout and redband trout, as well as changes in the population dynamics of brook trout.

OBJECTIVES

1. Assess whether three years of electrofishing removals could eliminate or suppress brook trout and increase abundance of native salmonids in subsequent years.

2. Assess whether any brook trout that evaded capture underwent any compensatory responses such as decreased natural mortality, increased growth, increased fecundity at length, or earlier maturation.

METHODS

The project occurred on Pikes Fork, a second-order tributary to the Boise River, which is itself a tributary to the Snake River in southwestern Idaho. Mean summer stream wetted width, gradient, and elevation in the 7.8 km reach of treated stream were 2.8 m, 3.0%, and 1,750 m, respectively. The Pikes Fork drainage has been logged extensively, but riparian and stream habitat conditions have remained reasonably unaltered. At the start of this study, Pikes Fork contained brook trout, redband trout, a small population of bull trout, and shorthead sculpin *Cottus confusus*. Sterile catchable rainbow trout *O. mykiss* are stocked about 3 km downstream of the study area.

From 1998 to 2000, brook trout were removed annually during a three-day period in mid August. Each year the stream was sectioned into 200-400 m reaches with block nets. Crews of four to eight people performed a two-pass electrofishing removal in each reach using two gas- and/or battery-powered backpack electrofishing units and several netters with dip nets. One electrofishing operator with a pair of netters proceeded about 20 m upstream of the other during a single depletion pass by a crew. Thus, although in essence the methods used resulted in a 4-pass removal effort with limited stream rest between the 2nd and 3rd passes, the WAG conducting the removal effort considered each of these 2-shocker unit runs a single pass, and we analyzed them as such.

Brook trout were measured (to the nearest millimeter total length, TL) and weighed (to the nearest gram), overdosed with anesthetic, and retained (frozen) for population dynamics analyses. Redband trout and bull trout were measured, weighed, and released in the reach from which they were captured.

In 1998, the WAG performed removals in the lower 4.5 km of stream, and at that time, it was discovered that brook trout extended farther upstream than originally suspected. Before the second year of removal, spot surveys were used to more accurately determine brook trout distribution. Subsequently, 7.8 km of stream were electrofished in 1999 and 2000. Due to personnel shortages in 2000, removals were not as rigorous as in the previous two years. In this third year of removal efforts, two crews of four people, each with two backpack electrofishing units and two netters, were established for each day, and each crew covered one reach at a time. The crews made one or two depletion passes in the same manner as in previous years.

After removal efforts in 1998, a wire gabion barrier was constructed at the bottom of the treated section of stream by the U.S. Forest Service. The barrier and downstream plunge-pool were designed with a minimum jumping pool of 0.6 m and a vertical drop of 0.5 m at flood stage and 0.8 m at low flow. This design was supposed to prevent upstream migration by resident brook trout, while allowing migratory bull trout (fish >400 mm TL) to scale the barrier (T. Burton, Bureau of Land Management, personal communication). In 1999, we attempted to assess the effectiveness of the barrier. In a 300 meter reach of stream directly below the barrier, 50 brook trout ≥150 mm were marked four weeks prior to the electrofishing removals. None were recaptured during subsequent removals in any of the following years.

Abundance, upper and lower 95% confidence intervals (CIs), and capture probability (CP) for each species in each reach were estimated with the maximum-likelihood model using MicroFish (Van Deventer and Platts 1989). If the calculated lower 95% CI were less than the actual number of brook captured and removed, we used the number captured as the lower CI. Because electrofishing is size selective (Reynolds 1996), and in order to monitor yearly recruitment success, estimates were made separately for age-0 (<80 mm) and age-1 and older (≥80 mm) fish. For reaches where only one removal pass was made in 2000, estimates of abundance were made by developing, from the multipass reaches, a linear relationship between the numbers of trout captured in first passes and subsequent maximum-likelihood abundance estimates. From these relationships, we predicted trout abundance (and 95% prediction intervals) for the reaches where only a single removal pass was made (cf. Lobón-Cerviá et al. 1994; Jones and Stockwell 1995; Kruse et al. 1998). Separate regression models were built for trout <80 and ≥80 mm. The entire stream was sampled with the above methodology, and estimates of total abundance and CIs for all species were calculated by summing the estimates from all reaches.

Although capture probability from multipass removals averaged 0.78, we realize this was probably an overestimate (Riley and Fausch 1992; Peterson et al. 2004b), and subsequently that population estimates for trout and removal efficiencies for brook trout were probably underestimated and overestimated, respectively (especially for age-0 fish). Catch curve results from 1998 and 2000 indicated that age-1 brook trout were probably not fully recruited to the sampling gear, and thus the abundance modeling assumption of equal catchability between size classes ≥80 mm was probably violated. This may have further biased our estimates of abundance and removal efficiency of age-1 and older brook trout.

Surveys were repeated in mid August 2003 to compare abundance and population dynamics of brook trout after three years of no removals to the treatment years. Instead of surveying the entire stream, we randomly selected 12 100 m reaches for multipass electrofishing. Abundance for the 7.8 km stream was estimated as the average abundance per 100 m reach surveyed times 78. Formulas for population totals and CIs were from Scheaffer et al. (1996).

The removed brook trout were thawed in the laboratory. Sagittal otoliths were removed and stored dry in vials. Scales were removed above the lateral line and posterior to the dorsal fin, spread on strips of paper, and stored in envelopes. Because scale readings often underestimate age compared to otolith readings (Beamish and McFarlane 1987), age was estimated primarily by viewing whole otoliths, dry or submersed in saline, with a dissecting microscope using reflected and/or transmitted light. In the few instances when age from otoliths could not be estimated (n = 14), we pressed scales on acetate slides with a heat press at 10,000 PSI and 110°C for 20-30 s and viewed them with a microfiche reader. We aged a subsample (n = 1,775) of brook trout that were retained during the study (n = 3,532) and estimated age for the remaining fish using an age-length key (DeVries and Frie 1996). Readers had no knowledge of fish length during readings. The mean index of average error (Beamish and Fournier 1981) between readers for all aged brook trout was 4.9%. When discrepancies between readers occurred, differences were resolved with additional joint readings, and when discrepancies could not be resolved, results for that fish were discarded. All fish were considered one-year-old when they reached their first January.

Gender and maturity were determined by examination of the gonads. Males were classified as immature if testes were opaque and threadlike, and mature if they were large and milky white. Females were classified as immature if the ovaries were small, granular, and translucent, and mature if they contained large, well-developed eggs that filled much of the abdominal cavity (Strange 1996). Eggs were counted from 89 mature females across all years. Curvilinear (i.e. power function) regression equations relating fish length to fecundity were developed separately for each year. To test for changes in fecundity-at-length between years, we log transformed the fecundity data to create a linear relationship with fish length, then used analysis of covariance to compare slopes (ß) and elevations of the regressions (α) following Zar (1996).

Following Robson and Chapman (1961), we estimated total annual survival rate (S) and 95% CIs using catch curve analysis. Only age-2 and older brook trout were fully recruited to the electrofishing gear and thus useable for survival estimates. Catch-curve analysis requires that 1) S is uniform with age and does not change over time, 2) the population is sampled randomly, and 3) recruitment is constant each year. We may have violated assumptions (1) and (3) in the second and third year of our study, because the removals may have increased total mortality and decreased recruitment. One method of avoiding the necessity of such assumptions is to track abundance (or catch per unit effort) of particular age classes through time (Ricker 1975); for comparative survival estimates, we attempted this to the extent possible but were limited by methodology constraints. We believe the use of catch-curve analysis was justified for several reasons. First, S for the first year was unaffected by any removals and is therefore unbiased. Second, although recruitment was variable, Allen (1997) showed that if the coefficient of variation (CV) of recruitment is 80% or less, estimates of S should be within ± 10%. In our study, CV was estimated to be 77.4 and 81.0% for age-0 and age-1 brook trout, respectively. Third, the removal efforts should have increased the negative slope of the catch curve, resulting in an increase in total mortality. A lack of such an increase would be evidence that the assumption of uniform S with age and over time was not violated.

Growth was assessed by calculating the mean length at age (and 95% CIs) from the age-length keys (DeVries and Frie 1996). Because size-at-age between years is not independent (i.e. small age-1 fish in one year may result in small age-2 fish the following year, with no difference in incremental growth compared to other years), we also compared incremental growth between years to assess removal effects or compensatory responses. Changes in size structure were assessed by comparing cumulative length frequencies with a Kolmogorov-Smirnov goodness of fit procedure (correcting for multiple inference tests by using the sequential Bonferroni technique; see Rice 1989). To evaluate sex ratio, we calculated 95% CIs around the percentage of the population that was female, using the formulas in Fleiss (1981); CIs not overlapping 50% indicated a statistically significant departure from a 50:50 ratio.

We characterized length and age at maturity each year by developing logistic regression models to estimate the length and age at which the probability of being mature was 0.5 (termed maturity transition points; see Meyer et al. 2003). Each fish was considered a sample unit, and a binary dependent variable was used for maturity (i.e. 0 = immature, 1 = mature) and was related to the independent variables of fish length and fish age. Separate estimates were developed for males and females, since males tended to mature at a smaller size than females and because selection forces for size-at-maturity differ between sexes (Roff 1992). We calculated 95% CIs around the length- and age-based maturity transition points and compared estimates between years to assess whether any compensatory responses occurred.

RESULTS

A total of 1,401, 1,241, and 890 brook trout were removed in 1998, 1999, and 2000, respectively. In 1999 and 2000, such removals constituted an estimated 88 and 79% of the number of brook trout present, respectively; no such estimate could be made in 1998 because the entire stream was not treated. Personnel expenditure totaled 210 person-days for electrofishing removals alone and did not include project planning, coordination, or barrier installation.

Abundance

Because the upper reaches were not treated in 1998, abundance between all years could only be compared for the lower 4.5 km of stream. In this portion of the stream, abundance of age-1 and older brook trout did not decrease from August 1998 to August 1999 despite removing an estimated 98% (based on the total number removed compared to the total estimate of abundance) of the brook trout present in that section (Table 1). However, abundance decreased significantly in 2000 and 2003 relative to 1998 (Figure 1). Abundance of age-0 brook trout decreased dramatically from 1998 to 1999 and remained low in 2000, but by 2003 age-0 abundance had rebounded. For the entire 7.8 km of stream, age-1 and older brook trout appeared to have decreased markedly, but in 2003 an estimated 655 fish remained. Abundance of age-0 brook trout was low in 1999 and 2000, but after two years with no removals, abundance increased to 1,832 fish. Removal efficiencies in 1998 were high, but again, only the lower portion of the stream was treated. In the two years when the entire stream was treated, removal efficiency averaged 89 and 64% for age-1+ and age-0 brook trout, respectively.

While brook trout were being removed, there was no consistent increase in abundance of redband trout (Figure 1). Abundance of age-1 and older redband trout remained relatively constant during the removal years, but by 2003, abundance decreased substantially. Abundance of age-0 redband trout increased after the second year of removal but by 2003 had decreased to levels similar to the pretreatment period. Only nine bull trout were encountered in the first two years of removals (four in 1998 and five in 1999), and none in subsequent years.

Demographic parameters

Changes in the redband trout and brook trout populations were also evident when comparing size structure of fish in Pikes Fork (Figure 2). Brook trout cumulative length frequency was significantly different between all years, with the frequency of age-0 brook trout declining from 1998 to 1999 ($P < 0.001$), rebounding in 2000 ($P < 0.001$), and increasing in 2003 ($P < 0.001$) when there were few larger brook trout. The first year of removal appeared to have little effect on the cumulative length frequency of redband trout, but in 2000, after two years of brook trout removal, a larger percentage of redband trout were less than 150 mm than in previous years ($P < 0.001$). By 2003, the cumulative length frequency of redband trout was not different from before the project started ($P = 0.30$).

Age-2 and younger brook trout comprised 91-100% of all brook trout present from 1998 to 2003 (Figure 3). During all years of the study, only 2% were age-4 or older. Brook trout growth varied between year classes and study years and may have been affected by the removal efforts. For example, age-0 brook trout were significantly larger in 2000 (the year after abundance was lowest) than in other years (Figure 4). Also, age-1 and age-2 brook trout were significantly smaller following the initial removal years but recovered by 2003 (Figure 4). Growth slowed as fish aged, but there were no prominent patterns between years regarding incremental growth (Figure 4).

Total annual survival rate was low in all years (Figure 5). Based on catch curves, S was an estimated 0.08 ± 0.02 in 1998, 0.20 ± 0.04 in 1999, and 0.21 ± 0.04 in 2000. No estimate could be made in 2003, because no fish over age-2 were captured. Cohort analysis also supported the fact that S was low. In the lower 4.5 km of Pikes Fork, S from 1998 to 1999 estimated for individual age classes was 0.10 from age-2 to age-3 and 0.16 from age-3 to age-4 (Table 2). Over all age classes, S was estimated to be 0.11. Similarly, from 1999 to 2000 S was estimated to be 0.08 for the lower portion of Pikes Fork and 0.19 for the entire stream (Table 2). We tended to catch older brook trout as the removals continued. The oldest brook trout observed was age-3 in 1998, age-4 in 1999, and age-5 in 2000, while in 2003, after no removals were performed for two years, the oldest brook trout was age-2.

The length-weight relationship was nearly identical between all years (Figure 6). Fish-length vs. fecundity regressions did not differ between years for slope ($P = 0.18$) or elevation ($P = 0.13$; Figure 7), although sample sizes were small for some years and the resultant power of this test was low. Of the brook trout whose sex could be determined, females significantly outnumbered males only in 2000 when the proportion of brook trout that were female was 0.59 ± 0.06.

Length- and age-at-maturity for brook trout changed little over the course of the study (Figures 8 and 9). In all years, there was always a higher proportion of mature males than females for each age class (Figure 8), most notably for ages 1 and 2. The smallest mature male and female brook trout were both 95 mm, while the largest immature male and female brook trout were 157 and 188 mm, respectively. Length-based maturity transition points averaged 124.5 mm for male brook trout and 147.3 mm for female brook trout, and confidence bounds between genders did not overlap during any year (Figure 9). Although both male and female brook trout appeared to mature at a slightly smaller size after the removals began, this trend was not significant. Age-at-maturity transition point models were less precise than length-based models, but the patterns were the same as for length-at-maturity.

DISCUSSION

Three years of intensive electrofishing removals had few long-term effects on the abundance of brook trout in Pikes Fork, and there was no noticeable increase in redband trout abundance over the course of the study. Although abundance of age-1 and older brook trout declined 86% in the lower 4.5 km of stream and 44% in the entire stream, age-0 brook trout decreased only 35% in the lower portion of the stream and increased 789% in the entire stream. Concurrently, redband trout showed no signs of increase, and bull trout appeared to be absent by the end of the study, although only a few bull trout were captured even in the first years of removal.

Lack of meaningful decline in abundance of brook trout, coupled with the lack of an increase in total mortality of age-2 and older brook trout during removal treatments, suggests a compensatory response occurred in the brook trout population via reduced natural mortality, which offset the removal of large numbers of brook trout. McFadden (1977) pointed out the logical necessity that, if a population is at equilibrium, any increase in mortality (in this study, ‘fishing’ mortality caused by our exploitation) must be compensated for in some manner or the population will be extirpated. Any brook trout that avoided the heavy exploitation in this study would have experienced much less competition for food and space (Chapman 1966). That increases in growth were not observed for all ages while abundance was lower during the removal years (age-1 and age-2 growth actually decreased during the removal treatments) may have been due in part to yearly exposure of the entire population, including those that escaped capture, to electrofishing, which can reduce growth rate (Dalbey et al. 1996; Thompson et al. 1997). Also, older fish theoretically could have been putting more energy into reproduction instead of growth, although we saw no indication of this in fecundity or maturity changes. A more likely explanation was given by McFadden (1977), who argued that the complexity of interactions between several compensatory response mechanisms might lead to the operation of one mechanism under certain environmental conditions, preempting the operation of other mechanisms.

In addition to their compensatory abilities, brook trout have the propensity to achieve maturation at an early age. Because age-0 fish are difficult to capture with electrofishing gear, it was difficult to remove all brook trout before they had the chance to spawn at least once. For example, the average length of age-1 brook trout in Pikes Fork was 110 mm and over half (54%) of these fish were mature. Thus, if an individual brook trout was not captured as a fry and escaped capture again at age-1, more often than not that fish was mature and could then spawn that fall.

Our estimates of S may have been biased because we clearly violated the assumptions of constant year-class strength and uniform survival rates for all age groups used in the calculation (i.e. age-2 and older; Ricker 1975). However, the fact that S was extremely low in 1998 (before any bias could have occurred) and the agreement we saw with cohort analysis supports the conclusion that brook trout mortality was naturally very high in Pikes Fork. Such high mortality is common for brook trout populations in small streams (McFadden 1961; Phinney 1975).

Factors other than compensation may explain some or all of the lack of decline in brook trout abundance in Pikes Fork. First, we probably underestimated population abundance and overestimated removal efficiencies, since depletion estimates typically underestimate true abundance, especially for smaller fish and when only two passes are made (Riley and Fausch 1992; Peterson et al. 2004b). Also, it is possible that some (but probably not many) brook trout ascended the barrier that was designed for their exclusion. We captured two 250–300 mm hatchery rainbow trout above the barrier in 2000, despite the fact that the nearest IDFG fish stocking location is downstream a few kilometers in the Crooked River (B. Turik, IDFG Nampa Hatchery, personal communication). Unless these fish were illegally transported by an angler, they ascended the barrier. Although in subsequent years we never captured any of the brook trout that were marked below the barrier prior to the 1999 removals, we only marked 50 fish so our ability to determine upstream movement was poor. Adams et al. (2000) found similar-sized brook trout to those in Pikes Fork ascending drops that were 0.5–1.2 m in height.

Because we did not have a control stream, we cannot be certain that environmental conditions did not confound our results. For example, increased growth or survival conditions during the removal years could have produced the changes we have attributed to compensation. We could not incorporate a control stream in our study design because the criteria for such a control (i.e. a very small stream, but one from which we could remove hundreds of brook trout for demographics comparisons to the treatment stream) necessarily excluded it as a true control (i.e. no manipulation). However, even if the changes in growth and survival we observed were caused by confounding factors, that does not discount the fact that the brook trout population in Pikes Fork, through one or several mechanisms, withstood an exorbitant amount of exploitation with little (if any) long-term changes to the population.

Other researchers have noted that brook trout can readily withstand electrofishing eradication efforts (Thompson and Rahel 1996; Buktenica et al. 2000). Successful electrofishing removal projects have usually only occurred in very narrow, short streams (<3 km) with simple habitat that were electrofished several times per year and/or for several consecutive years (Kulp and Moore 2000; Shepard et al. 2002). Whether or not eradication projects are worthwhile depends on the removal results, the amount of habitat restored to native fish assemblages, and the expenditure of time and money on the project. For the project we evaluated, about 210 person-days were expended in three years during the electrofishing treatments alone. Although there were a number of volunteers, most person-days came from permanent or temporary employees of the organizations involved in the removal. Nevertheless, trying to be conservative, we assumed an average salary (with benefits) of USD $10/hour, an average field day of 10 hours, average per diem of $20/day, $200/week for vehicle leasing and operation (one vehicle per two people), and $15,000 for barrier installation. Using these figures, the eradication effort cost about $61,200, or $7,846 per km of stream treated. Comparably, Shepard et al. (2002) estimated that $10,000/km was spent to successfully remove brook trout in their study, not including the cost of the barrier.

Electrofishing was not an effective method for removing brook trout from Pikes Fork but may have been more successful if the methodology of the most successful electrofishing removal projects had been followed. Such projects have used less intensity (spreading removals over the entire year), higher frequency (more treatments per year), and longer duration (more years of treatment). Nevertheless, we question whether use of electrofishing methods to eliminate brook trout populations will ever prove cost-effective or practical for an appreciable proportion of waters in the western United States. Meyer et al. (in review) estimated that in the Upper Snake River basin of Idaho alone, there were roughly 1.2 million brook trout present. Based on the costs of this project, the number of brook trout removed, and the distance covered, we estimate it would cost over $1 million to perform electrofishing removals in only 5% of the range of brook trout in the Upper Snake River basin, and most likely these removal efforts would rarely be successful in completely eliminating brook trout.

In summary, our results suggest that electrofishing removals in Pikes Fork were unsuccessful because mortality within the brook trout population was extremely high prior to initiation of the project, such that the removal efforts merely replaced natural mortality with exploitation. Except in very short, narrow streams with simple habitat, our results and those of many others suggest that electrofishing removals are likely to be unsuccessful in completely eradicating brook trout. Because brook trout clearly have the ability to outcompete many of the native salmonids in the western United States, undertaking removal projects with a goal of merely reducing brook trout density or initiating efforts over large stream lengths with little hope for total eradication would seem a costly but quixotic enterprise. Like Finlayson et al. (2005), we believe other methods, such as the use of chemical treatments with rotenone and antimycin, are likely to be more cost effective and successful at completely eradicating brook trout under most circumstances. We encourage others involved in brook trout eradication efforts using electrofishing to quantitatively monitor the cost-effectiveness of their project and response of the fish populations to shed more light on the utility of the technique.

RECOMMENDATIONS

1. Avoid using electrofishing as a removal technique for brook trout unless the treatment area is very short, simple in habitat, and other more effective techniques (such as chemical treatment) are not an option.

2. Monitor the effectiveness of each removal project relative to benefits to native salmonids and compensatory responses from any remaining nonnative target fish.

ACKNOWLEDGMENTS

The brook trout removal project was initiated and carried out by many people from a number of organizations, including Idaho Department of Environmental Quality; Idaho Department of Lands; U.S. Forest Service and Bureau of Reclamation; Boise Corporation; Idaho Department of Fish and Game; and numerous volunteers. Greg Batts, Jeff Rice, Win Taylor, Nick Frohnauer, and John Cassinelli assisted with aging and demographics analyses. Chris Downs, Bob Danehy, Jim Capurso, Steve Yundt, Andrew Paul, Claire McGrath, Alan Byrne, Rob Ryan, and James Peterson provided comments and suggestions that greatly improved the manuscript. Funding for our evaluation of the WAG removal project was provided by the Bonneville Power Administration.

LITERATURE CITED

Adams, S. B., C. A. Frissell, and B. E. Rieman. 2000. Movements of nonnative brook trout in relation to stream channel slope. Transactions of the American Fisheries Society 129:623-638.

Allan, J. D., and A. S. Flecker. 1993. Biodiversity conservation in running waters: identifying the major factors that threaten destruction of riverine species and ecosystems. Bioscience 43:32-43.

Allen, M. S. 1997. Effects of variable recruitment on catch-curve analysis for crappie populations. North American Journal of Fisheries Management 17:202-205.

Beamish, R. J., and D. A. Fournier. 1981. A method for comparing the precision of a set of age determinations. Canadian Journal of Fisheries and Aquatic Sciences 38:982-983.

Beamish, R. J., and G. A. McFarlane. 1987. Current trends in age determination methodology. Pages 15-42 *in* R. C. Summerfelt and G. E. Hall, editors. Age and growth of fish. Iowa State University Press. Ames, Iowa.

Buktenica, M. W., B. D. Mahoney, S. F. Girdner, and G. L. Larson. 2000. Response of a resident bull trout population to nine years of brook trout removal, Crater Lake National Park, Oregon. Pages 127-132 *in* D. Schill, S. Moore, P. Byorth, and B. Hamre, editors. Wild Trout VII: Management in the new millennium, are we ready? Yellowstone National Park, Wyoming.

Chapman, D. W. 1966. Food and space as regulators of salmonid populations in streams. The American Naturalist 100:345-357.

Cooper, E. L., J. A. Boccardy, and J. K. Anderson. 1962. Growth rate of brook trout at different population densities in a small infertile stream. The Progressive Fish Culturist 24:74-80.

Dalbey, S. R., T. E. McMahon, and W. Fredenberg. 1996. Effect of electrofishing pulse shape and electrofishing-induced spinal injury on long-term growth and survival of wild rainbow trout. North American Journal of Fisheries Management 16:560-569.

DeVries, D., and R. Frie. 1996. Determination of age and growth. Pages 483-512 *in* B. R. Murphy and D. W. Willis, editors. Fisheries Techniques, 2nd edition. American Fisheries Society. Bethesda, Maryland.

Donald, D. B., and D. J. Alger. 1989. Evaluation of exploitation as a means of improving growth in a stunted population of brook trout. North American Journal of Fisheries Management 9:177-183.

Dunham, J. B., S. B. Adams, R. E. Schroeter, and D. C. Novinger. 2002. Alien invasions in aquatic ecosystems: toward an understanding of brook trout invasions and potential impacts on inland cutthroat trout in western North America. Reviews in Fish Biology and Fisheries 12:373-391.

Fausch, K. D. 1988. Test of competition between native and introduced salmonids in streams: what have we learned? Canadian Journal of Fisheries and Aquatic Sciences 45:2238–2246.

Fausch, K. D. 1989. Do gradient and temperature affect distribution of and interactions between brook char and other salmonids in streams? Physiology and Ecology Japan, Special Volume 1:303–322.

Finlayson, B. and 11 coauthors. 2005. Native inland trout restoration on national forests in the Western United States: time for improvement? Fisheries 30(5):10-19.

Fleiss, J. L. 1981. Statistical methods for rates and proportions. John Wiley and Sons, Inc. New York, New York.

Fuller, P. L., L. G. Nico, and J. D. Williams. 1999. Nonindigenous fishes introduced into inland water of the United States. American Fisheries Society, Special Publication Number 27. Bethesda, Maryland.

Gresswell, R. E. 1991. Use of antimycin for removal of brook trout from a tributary of Yellowstone Lake. North American Journal of Fisheries Management 11:83-90.

Griffith, J. S. 1988. Review of competition between cutthroat trout and other salmonids. American Fisheries Society Symposium 4:134-140.

Jensen, A. L. 1971. Response of brook trout (*Salvelinus fontinalis*) populations to a fishery. Journal of the Fisheries Research Board of Canada 28:458-460.

Jones, M. L., and J. D. Stockwell. 1995. A rapid assessment procedure for the enumeration of salmonine populations in streams. North American Journal of Fisheries Management 15:551-562.

Krueger, C. C., and B. May. 1991. Ecological and genetic effects of salmonid introductions in North America. Canadian Journal of Fisheries and Aquatic Sciences 48:66-77.

Kruse, C. G., W. A. Hubert, and F. J. Rahel. 1998. Single-pass electrofishing predicts trout abundance in mountain streams with sparse habitat. North American Journal of Fisheries Management 18:940-946.

Kulp, M. A., and S. E. Moore. 2000. Multiple electrofishing removals for eliminating rainbow trout in a small southern Appalachian stream. North American Journal of Fisheries Management 20:259-266.

Larson, G. L., S. E. Moore, and D. C. Lee. 1986. Angling and electrofishing for removing nonnative rainbow trout from a stream in a national park. North American Journal of Fisheries Management 6:580-585.

Levin, P. S., S. Achord, B. E. Feist, and R. W. Zabel. 2002. Non-indigenous brook trout and the demise of Pacific salmon: a forgotten threat? Proceedings of the Royal Society of London 269:1663-1670.

Lobón-Cerviá, J., C. Utrilla, and E. Queirol. 1994. An evaluation of the 3-removal method with electrofishing techniques to estimate fish numbers in streams of the Brazilian Pampa. Archive for Hydrobiology 130:371-381.

McFadden, J. T. 1961. A population study of the brook trout *Salvelinus fontinalis*. Wildlife Monographs 7. 73 pp.

McFadden, J. T. 1976. Environmental impact assessment for fish populations. Pages 89-137 *in* P. Gustafson, editor. The biological significance of environmental impacts. University of Michigan. Ann Arbor, Michigan.

McFadden, J. T. 1977. An argument supporting the reality of compensation in fish populations and a plea to let them exercise it. Pages 153-183 *in* W. Van Winkle, editor. Proceedings of the conference on assessing the effects of power-plant-induced mortality on fish populations. Pergamon Press. New York, New York.

Meronek, T. G., and 8 coauthors. 1996. A review of fish control projects. North American Journal of Fisheries Management 16:63-74.

Meyer, K. A., D. J. Schill, F. S. Elle, and J. A. Lamansky. 2003. Reproductive demographics and factors that influence length at sexual maturity of Yellowstone cutthroat trout in Idaho. Transactions of the American Fisheries Society 132:183-195.

Meyer, K. A., D. J. Schill, and J. A. Lamansky. In review. Status of Yellowstone cutthroat trout in Idaho. Transactions of the American Fisheries Society.

Moore, S. E., B. Ridley, and G. L. Larson. 1983. Standing crops of brook trout concurrent with removal of rainbow trout from selected streams in Great Smoky Mountains National Park. North American Journal of Fisheries Management 3:72-80.

Moyle, P. B. 1986. Fish introductions into North America: patterns and ecological impact. Pages 27-43 in H. A. Mooney and J. A. Drake, editors. Ecology of biological invasions in North America and Hawaii. Springer-Verlag. New York, New York.

Paul, A. J., J. R. Post, and J. D. Stelfox. 2003. Can anglers influence the abundance of native and nonnative salmonids in a stream from the Canadian Rocky Mountains? North American Journal of Fisheries Management 23:109-119.

Peterson, D. P., K. D. Fausch, and G. C. White. 2004a. Population ecology of an invasion: effects of brook trout on native cutthroat trout. Ecological Applications 14:754-772.

Peterson, J. T., R. F. Thurow, and J. W. Guzevich. 2004b. An evaluation of multipass electrofishing for estimating the abundance of stream-dwelling salmonids. Transactions of the American Fisheries Society 133:462-475.

Phinney, D. E. 1975. Repopulation of an eradicated stream section by brook trout. Transactions of the American Fisheries Society 104:685-687.

Rahel, F. J. 2000. Homogenization of fish fauna across the United States. Science 288(5467):854-856.

Reynolds, J. B. 1996. Electrofishing. Pages 221-254 *in* B. Murphy and D. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society. Bethesda, Maryland.

Rice, W. R. 1989. Analyzing tables of statistical tests. Evolution 43:223-225.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191:382 pp.

Riley, S. C., and K. D. Fausch. 1992. Underestimation of trout population size by maximum-likelihood removal estimates in small streams. North American Journal of Fisheries Management 12:768-776.

Robson, D. S., and D. G. Chapman. 1961. Catch curves and mortality rates. Transactions of the American Fisheries Society 90:181-189.

Roff, D. A. 1992. The evolution of life histories: theory and analysis. Chapman & Hall, Inc. New York, New York.

Scheaffer, R. L., W. Mendenhall, and L. Ott. 1996. Elementary survey sampling, fifth edition. Duxbury Press. Belmont, California.

Shepard, B. B., R. Spoon, and L. Nelson. 2002. A native westslope cutthroat trout population responds positively after brook trout removal and habitat restoration. Intermountain Journal of Science 8:191-211.

Strange, R. J. 1996. Field examination of fishes. Pages 433-446 *in* B. R. Murphy and D. W. Willis, editors. Fisheries Techniques, 2nd edition. American Fisheries Society. Bethesda, Maryland.

Thompson, P. D., and F. J. Rahel. 1996. Evaluation of depletion-removal electrofishing of brook trout in small Rocky Mountain streams. North American Journal of Fisheries Management 16:332-339.

Thompson, K. G., E. P. Bergersen, and R. B. Nehring. 1997. Injuries to brown trout and rainbow trout induced by capture with pulsed direct current. North American Journal of Fisheries Management 17:141-153.

Van Deventer, J., and W. S. Platts. 1989. Microcomputer software system for generating population statistics from electrofishing data–user's guide for MicroFish 3.0. U.S. Forest Service, General Technical Report INT-254. Ogden, Utah.

Young, M. K. 1995. Conservation assessment for inland cutthroat trout. U.S. Forest Service, General Technical Report RM-GTR-256. Fort Collins, Colorado.

Young, M. K., B. K. Micek, and M. Rathbun. 2003. Probable pheromonal attraction of sexually mature brook trout to mature male conspecifics. North American Journal of Fisheries Management 23:276-282.

Zar, J. H. 1996. Biostatistical analysis. Third edition. Prentice Hall, Inc. Upper Saddle River, New Jersey.

Table 1. Estimated total abundance and confidence intervals (CIs), capture probabilities, and removal efficiencies for brook trout in Pikes Fork, Idaho based on August backpack electrofishing surveys. NA indicates parameters or years where results could not be estimated.

	Lower 4.5 km of stream					Entire 7.8 km of stream				
	Total brook trout abundance			Mean	Estimated	Total brook trout abundance			Mean	Estimated
Year	Lower 95% CI	Abundance estimate	Upper 95% CI	capture probability	removal efficiency	Lower 95% CI	Abundance estimate	Upper 95% CI	capture probability	removal efficiency
					Age-1 and older					
1998	688	699	725	0.83	0.98	---------------------------NA---------------------------				
1999	671	699	773	0.82	0.96	1127	1180	1312	0.81	0.96
2000	165	207	394	NA	0.42	510	629	973	NA	0.81
2003	48	100	152	0.82	-	376	655	935	0.81	-
					Age-0					
1998	713	796	890	0.69	0.90	---------------------------NA---------------------------				
1999	56	110	192	NA	0.29	114	224	390	NA	0.51
2000	156	198	369	NA	0.42	380	498	798	NA	0.76
2003	39	517	1157	0.62	-	1014	1832	2650	0.68	-

Table 2. Estimated total abundance of brook trout by stream reach and age group in Pikes Fork, Idaho. Dashed line represents cutoff where fish apparently became fully recruited to the electrofishing gear (see text) and where estimates became more reliable.

	Estimated total abundance of brook trout by stream reach																	
	Lower 4.5 km						Upper 3.2 km						Entire 7.8 km					
Age	1998	1999	2000	2001	2002	2003	1998	1999	2000	2001	2002	2003	1998	1999	2000	2001	2002	2003
0	796	110	198			517	NA	114	300			1315	NA	224	498			1832
1	198	455	106			83	NA	227	126			460	NA	683	228			543
2	457	191	81	Non-		17	NA	200	225	Non-		95	NA	389	308	Non-		112
3	44	46	20	removal		0	NA	49	62	removal		0	NA	95	82	removal		0
4	0	7	0	years		0	NA	5	9	years		0	NA	13	10	years		0
5	0	0	0			0	NA	0	0			0	NA	0	1			0
Total	1495	809	405			617	NA	596	721			2186	NA	1404	1127			2996

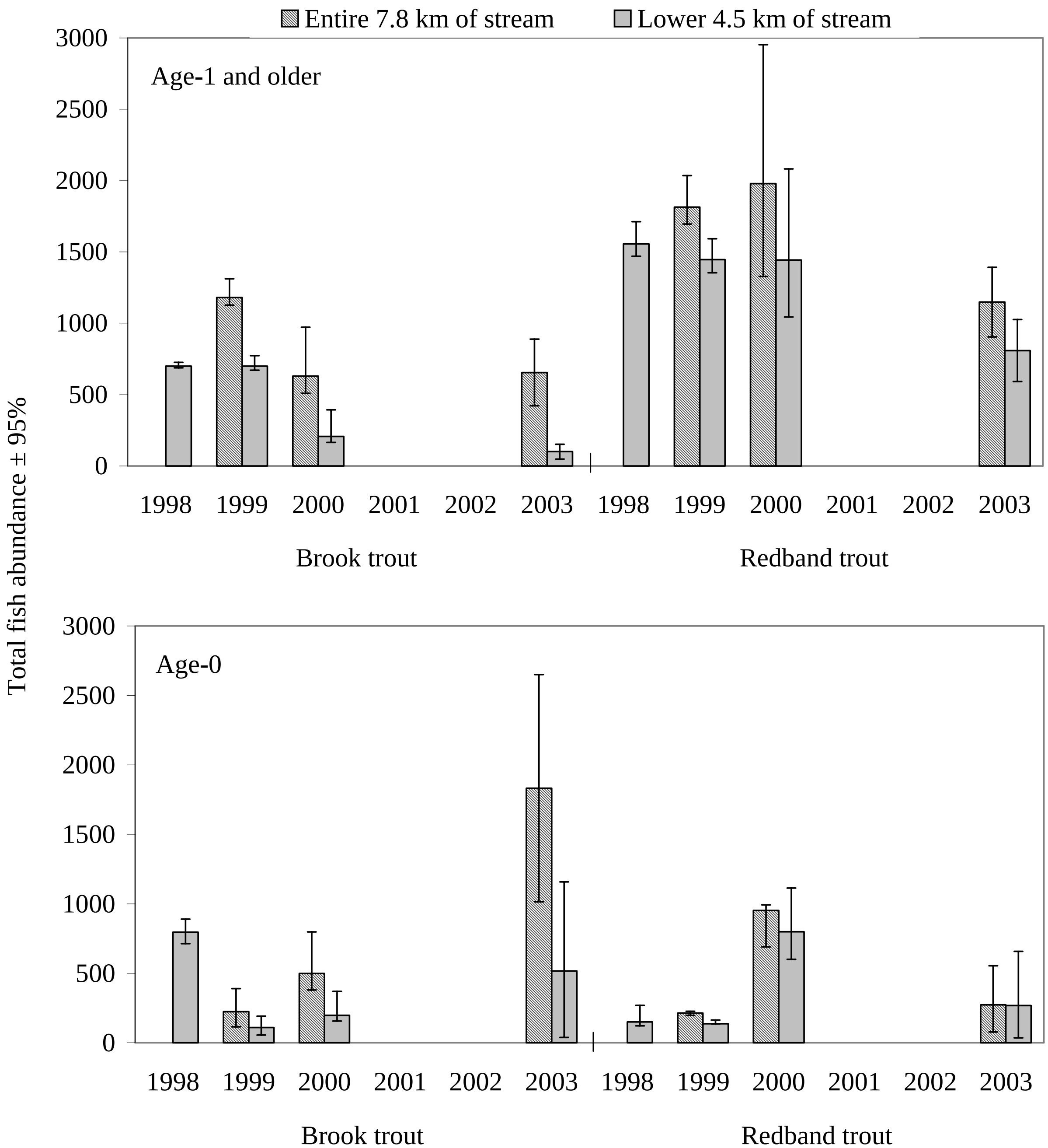

Figure 1. Total abundance (and 95% confidence intervals) of brook trout and redband trout from 1998 to 2003 in Pikes Fork, Idaho upstream of the manmade barrier. No removal treatments were made in 2001 and 2002.

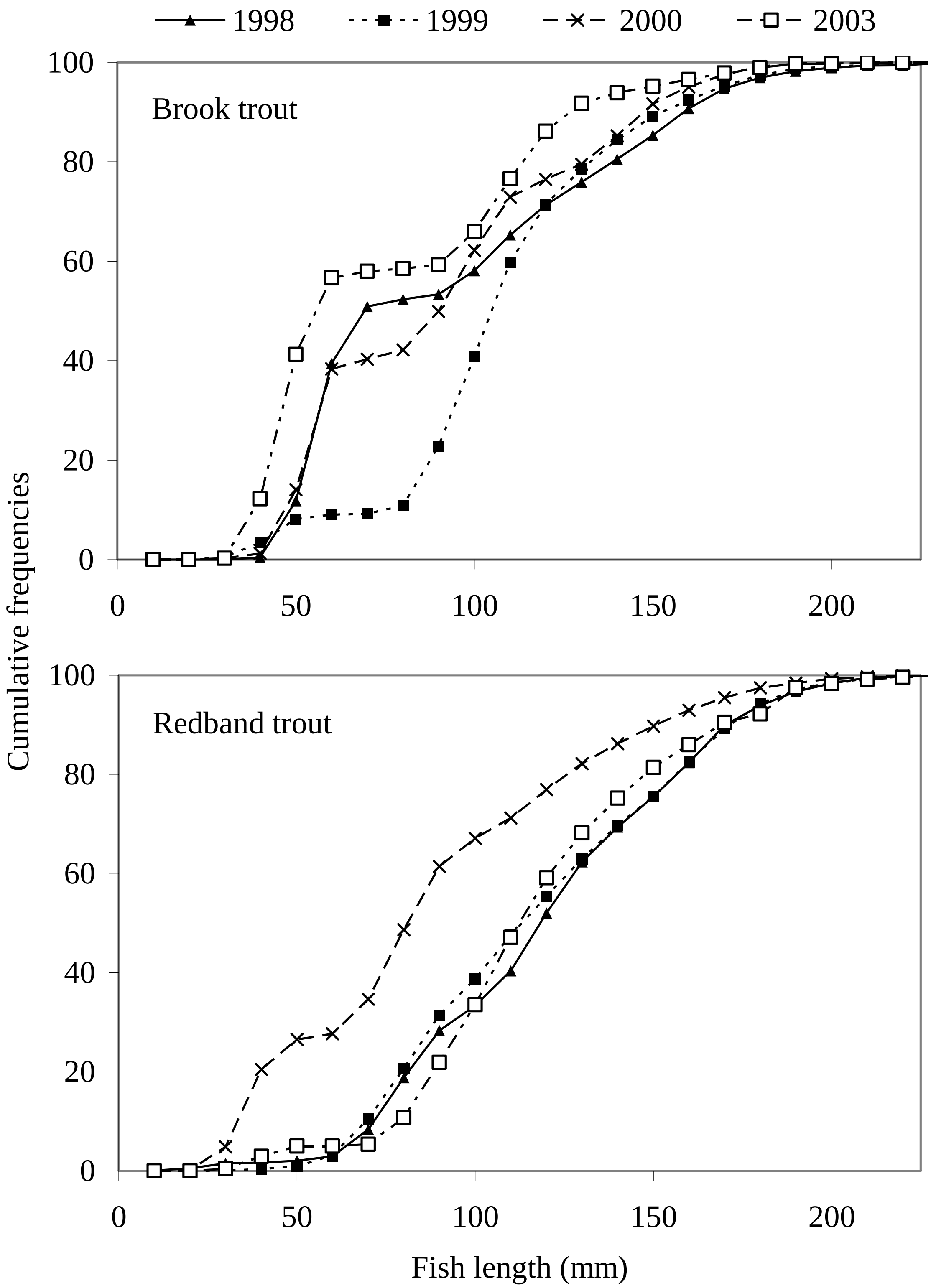

Figure 2. Cumulative length frequency of brook trout and redband trout from 1998 to 2003 in Pikes Fork, Idaho.

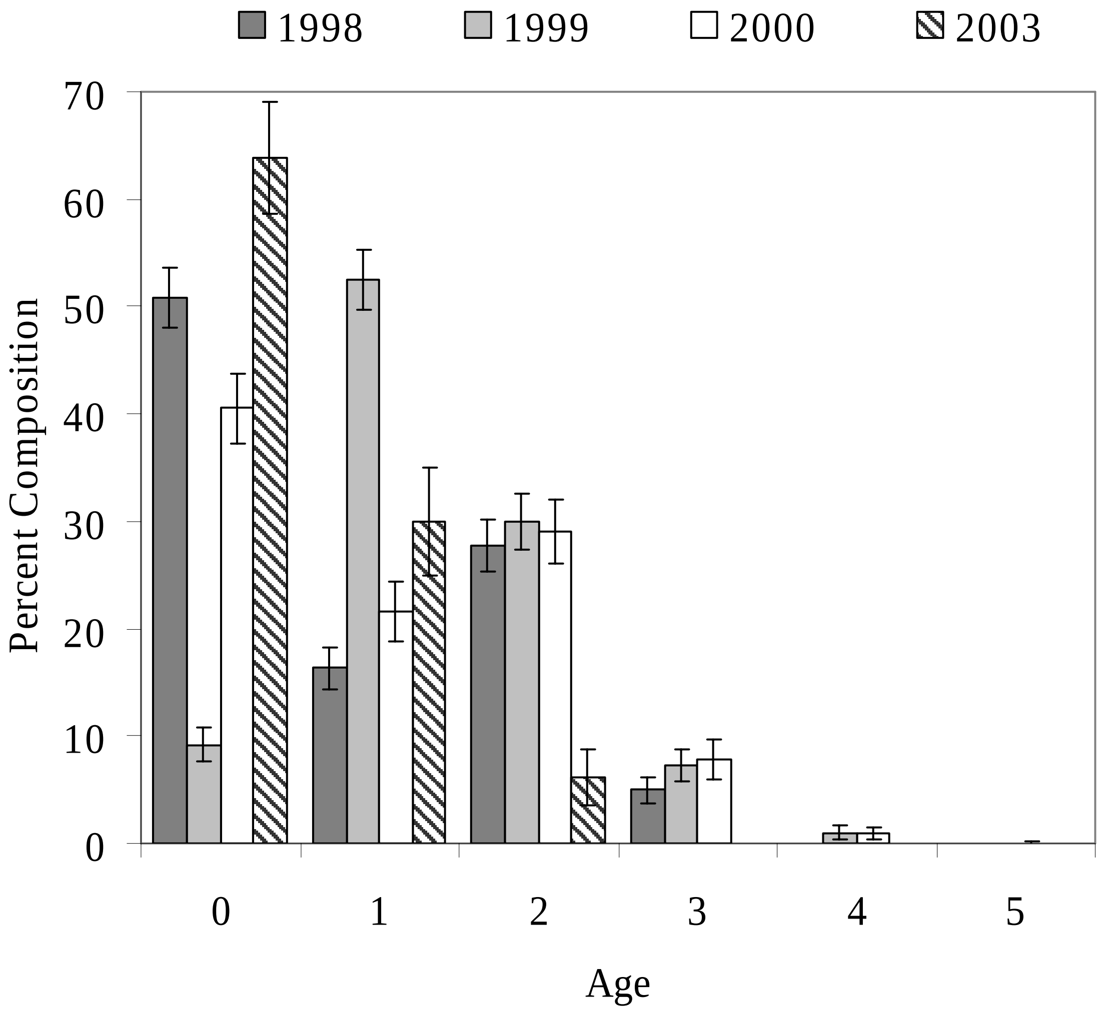

Figure 3. Percent composition of brook trout by age from 1998 to 2003 in Pikes Fork, Idaho. Bars represent 95% confidence intervals.

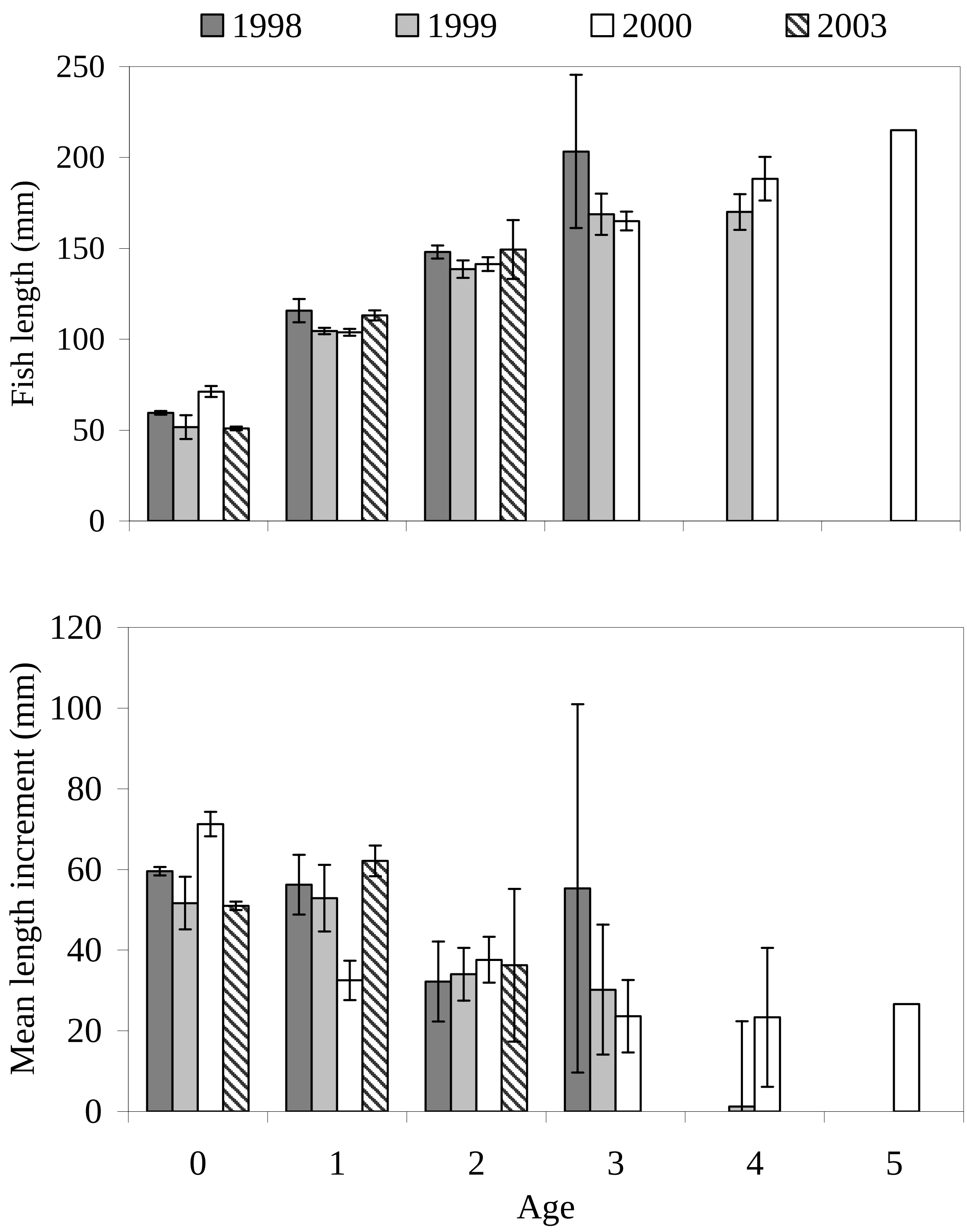

Figure 4. Mean length-at-age and mean length increment for brook trout from 1998 to 2003 in Pikes Fork, Idaho. Bars represent 95% confidence intervals.

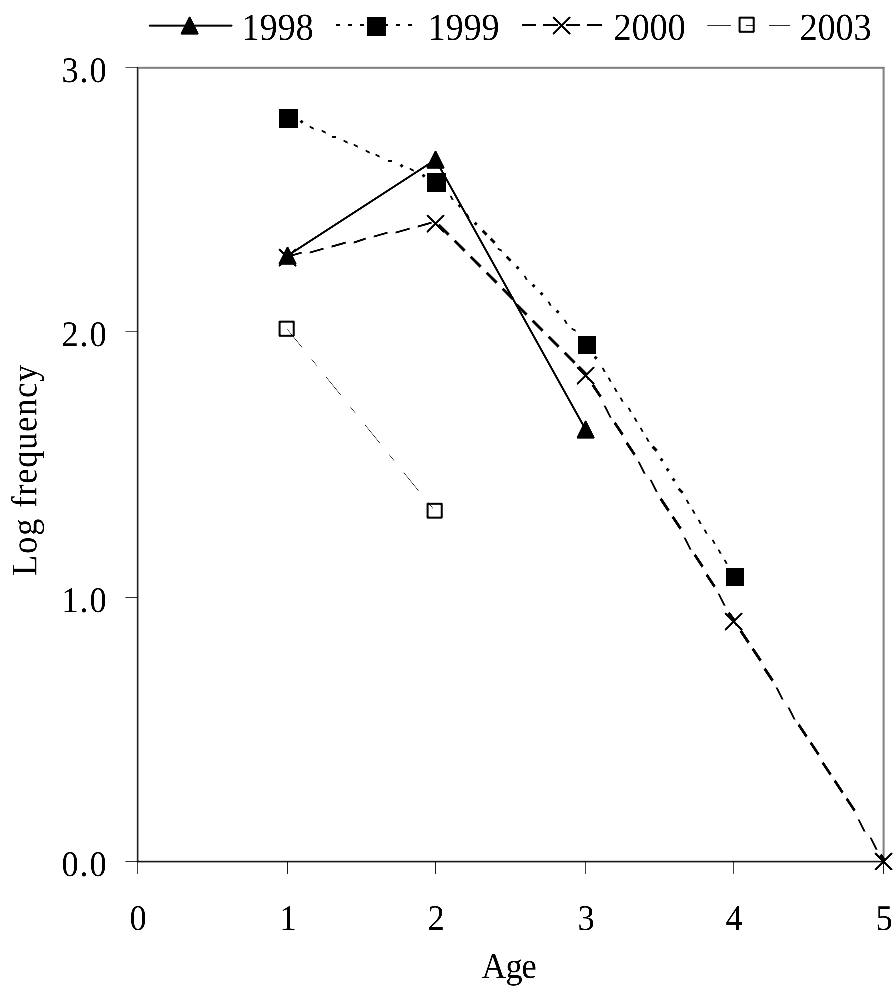

Figure 5. Catch curves for brook trout from 1998 to 2003 in Pikes Fork, Idaho.

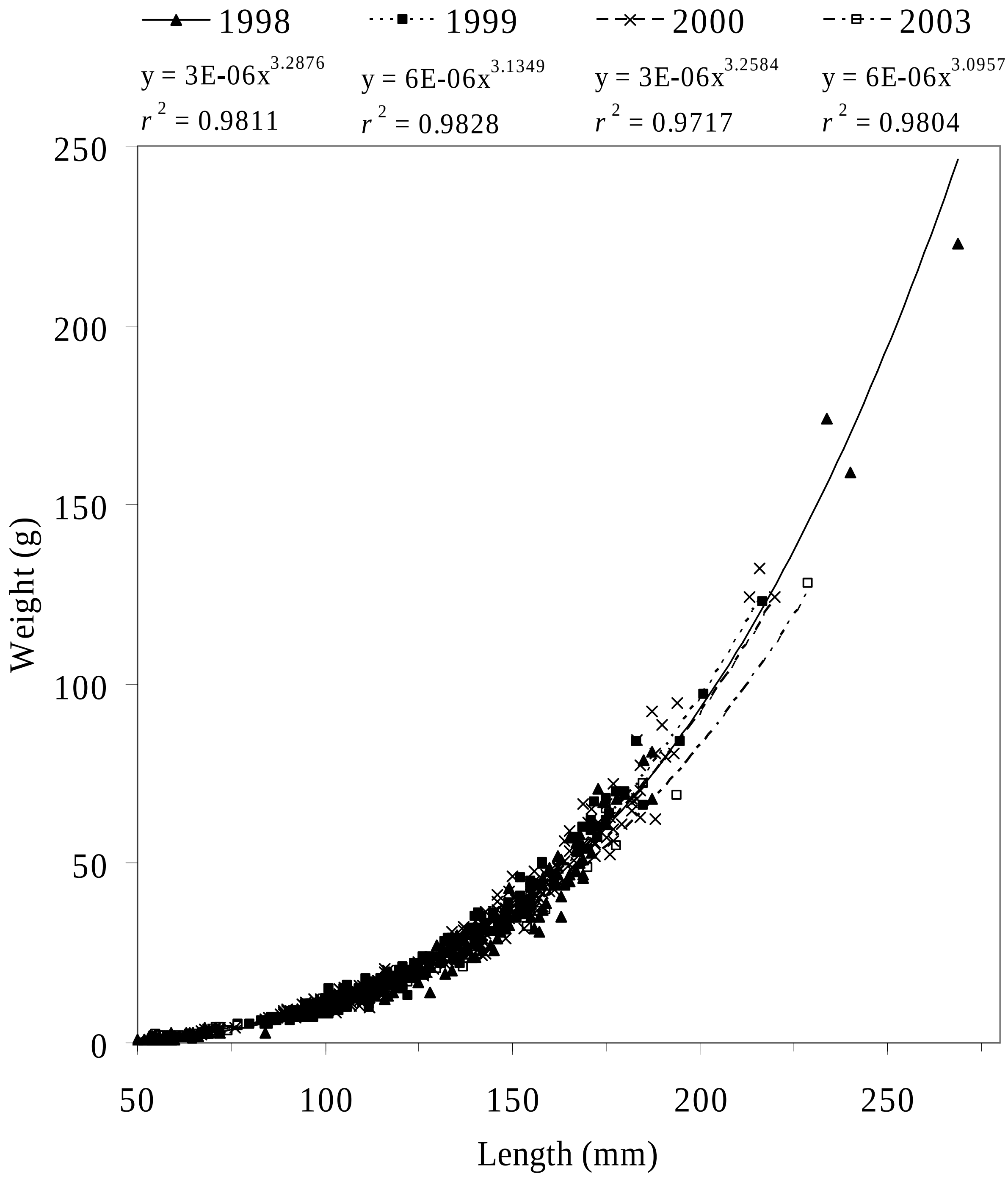

Figure 6. Length-weight relationship for brook trout from 1998 to 2003 in Pikes Fork, Idaho.

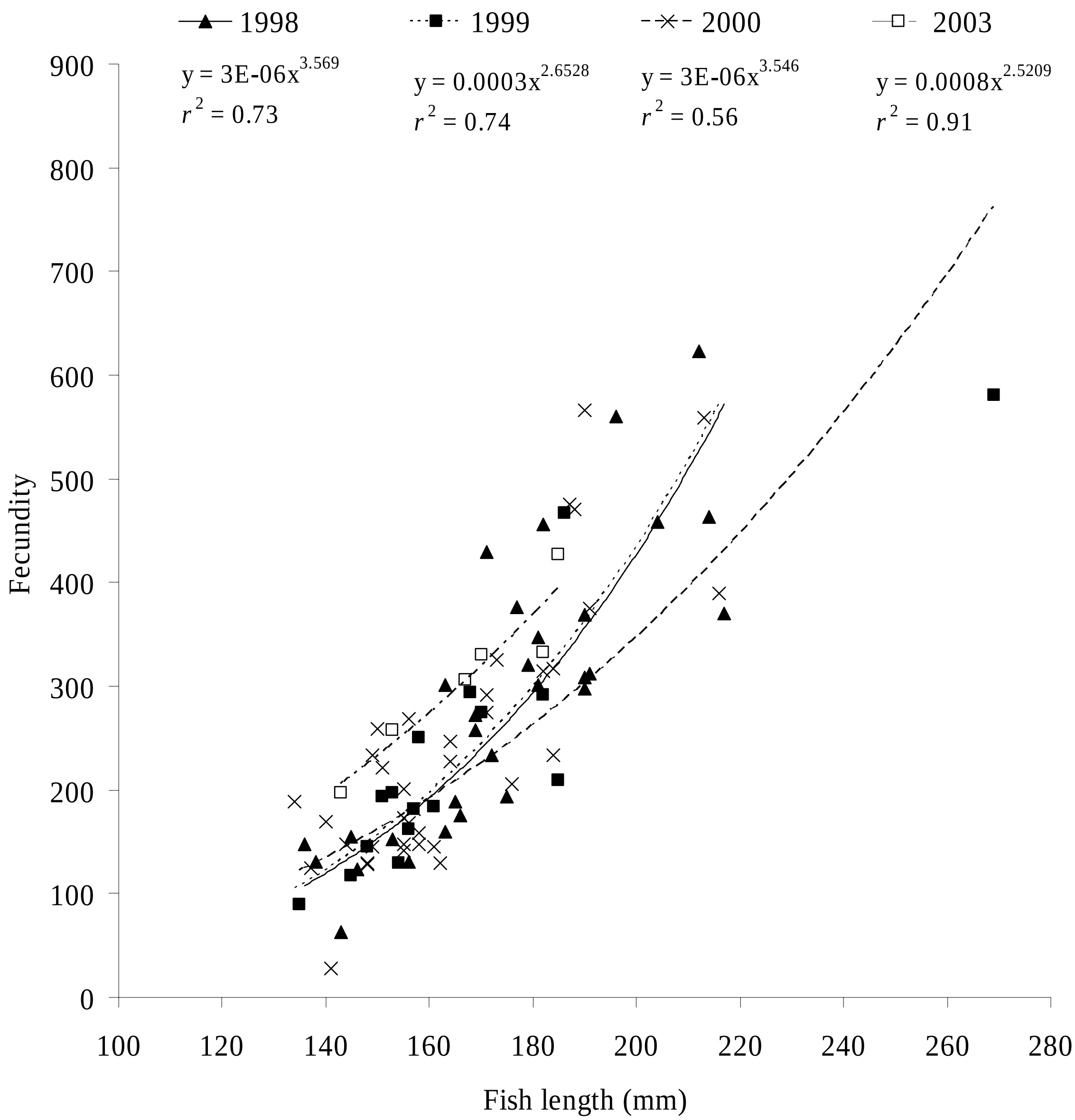

Figure 7. The relationship between fish length and fecundity of female brook trout from 1998 to 2003 in Pikes Fork, Idaho.

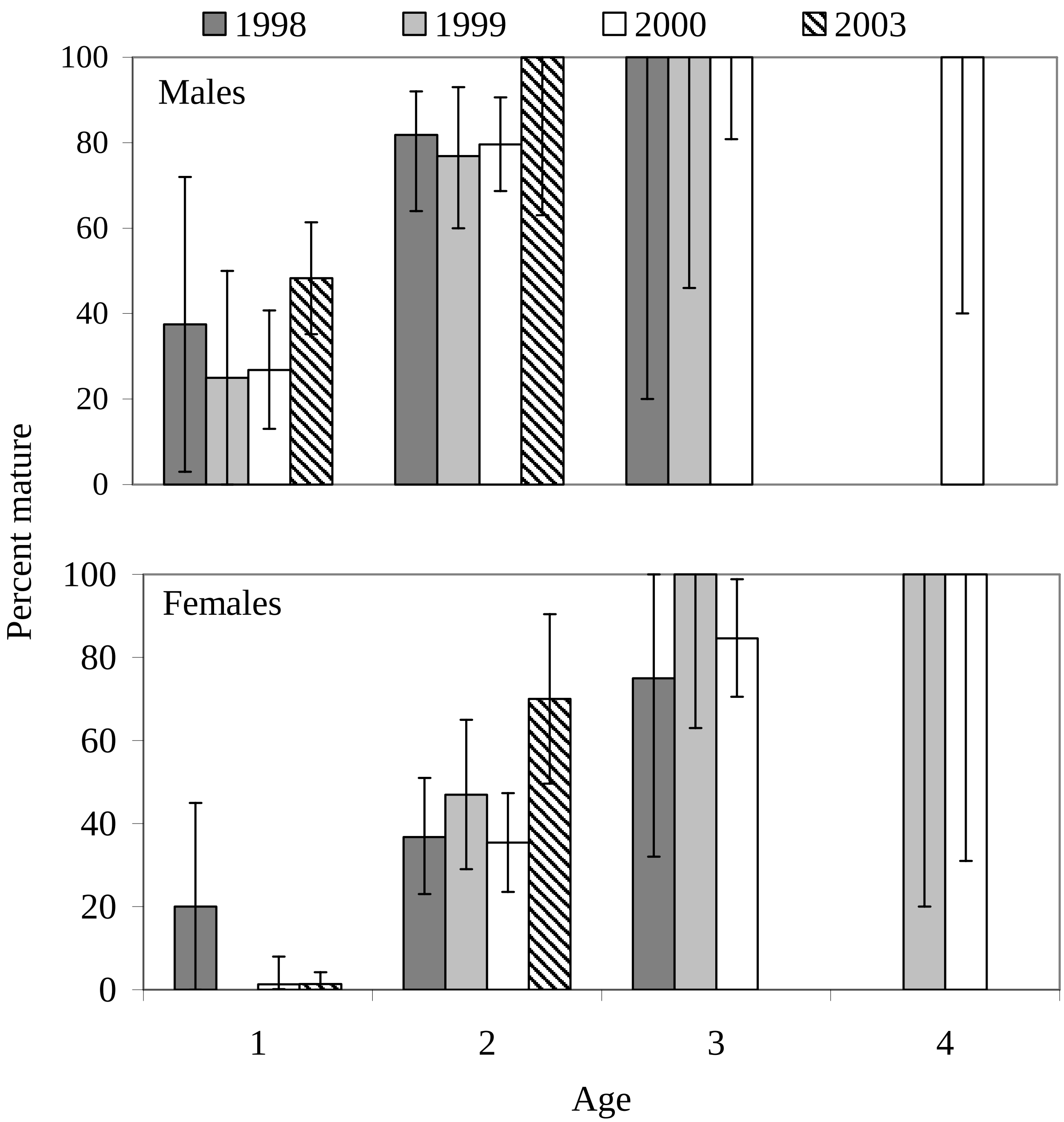

Figure 8. Proportion of male and female brook trout mature at age from 1998 to 2003 in Pikes Fork, Idaho. Bars represent 95% confidence intervals.

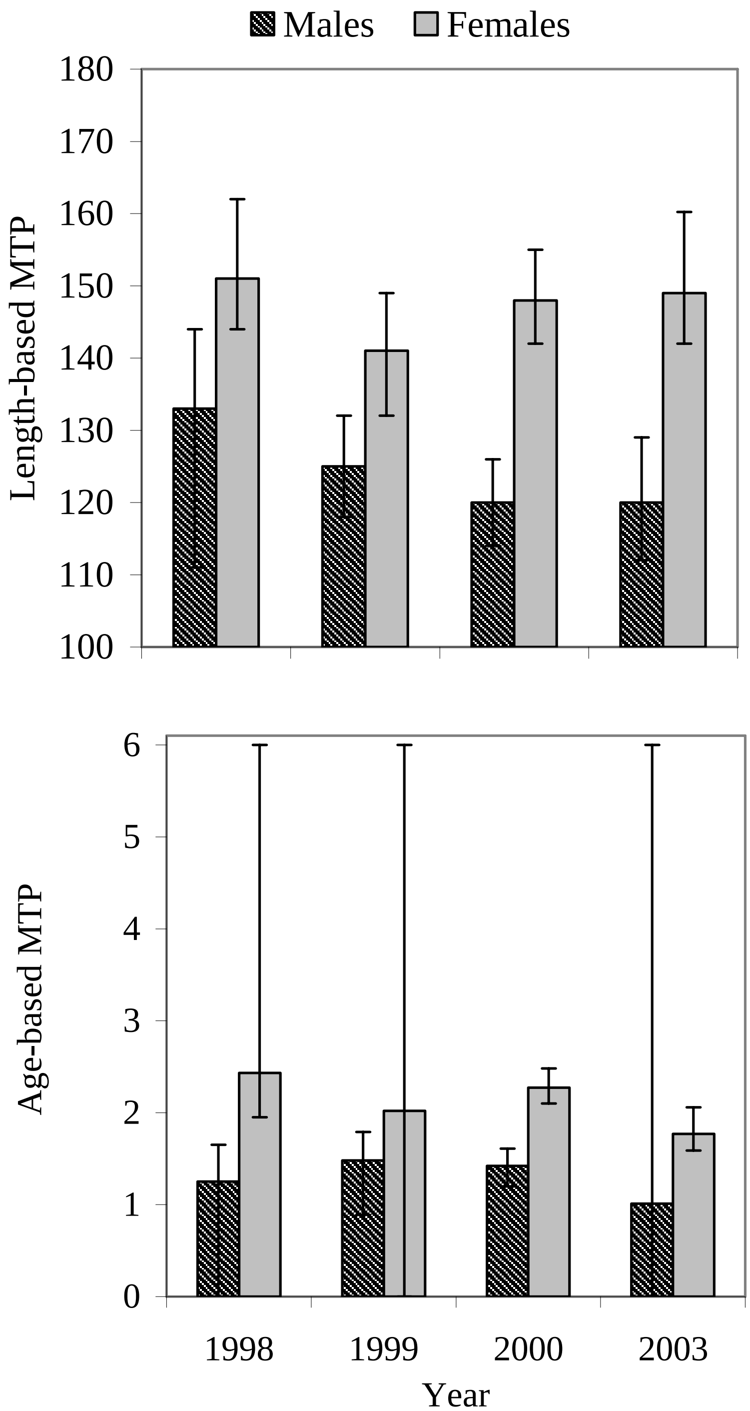

Figure 9. Length-based (mm) and age-based maturity transition points (MTP; where probability of being mature is 0.5) from logistic regression models for male and female brook trout from 1998 to 2003 in Pikes Fork, Idaho. Bars represent 95% confidence intervals.

PART #2: THE CAPTURE OF BROOK TROUT USING HOOP NETS SEEDED WITH MATURE CONSPECIFICS AS ATTRACTANTS

ABSTRACT

The introduction of nonnative species across the West has placed many native populations at risk, but existing methods for controlling nonnative species are usually time-consuming, expensive per unit of treatment, harmful to nontarget species, and often unsuccessful. An alternative method to reduce nonnative brook trout populations that may address some of those concerns is to remove them selectively by exploiting pheromonal attraction during spawning. We used five different combinations of brook trout (single male, three males, a male/female pair, a single female, and no fish) as treatments in hoop nets to test this approach. In 35 d of trapping, 1,360 brook trout were removed, of which 658 were mature, and 702 were immature. Of the mature brook trout, 83% were male and 17% were female. A significant difference in the number of mature male and immature brook trout captured across treatments was detected (P = 0.0025 and 0.043, respectively) but not mature females (P = 0.29). The male/female pair captured the highest number of mature brook trout (235); however, nets with no fish caught the second most (166). Our results suggest that brook trout may be attracted to mature conspecifics and may be used to attract them into hoop nets.

Authors:

James A. Lamansky, Jr.
Senior Fisheries Technician

Kevin A. Meyer
Principal Fisheries Research Biologist

INTRODUCTION

The impact of invasive species on the ecology of native species is widely recognized. The ecological basis of invasions can be described by the life history characteristics of the invader (Sakai et al. 2001). Life history traits common to successful invaders include the ability to use pioneering habitat, have high fecundity and short generation time, and be able to function in a wide range of physical conditions (Ehrlich 1989). Many plants and animals display these characteristics and are potential threats to natives when introduced in new areas. Brook trout are good invaders because they tolerate broad environmental conditions, express aggressive behavior, and possess the ability to reproduce at an early age (Moyle 1986).

Although brook trout have been historically stocked outside their native range to provide angling opportunities, they have further expanded their range and are currently found throughout the western United States (Thurow et al. 1997; Dunham et al. 2002). It has become clear that brook trout often competitively dominate or displace native salmonids (Griffith 1972; Fausch 1989) and pose a considerable threat to those fish (Dunham et al. 2002). Biologists are now attempting to remove brook trout in areas where their interaction with native salmonids is a concern, usually involving electrofishing or chemicals such as rotenone or antimycin (Gresswell 1991; Thompson and Rahel 1996; Reynolds 1996; Kulp and Moore 2000; Shepard et al. 2002). However, these methods pose several problems, including potential harm to the fish with electrofishing (Snyder 2003), danger to workers, acceptance by the public, or administrative problems using chemicals (Bettoli and Maceina 1996; Finlayson et al. 2005). The effectiveness of these methods is also variable and has proven time-consuming (Reynolds 1996; Thompson and Rahel 1996; Kulp and Moore 2000).

A method to remove brook trout that has been little studied entails using attractants, most likely pheromones, to lure brook trout into nets where they are passively captured and subsequently removed (Young et al. 2003). Several species of fish, including salmonids, can excrete chemicals that will elicit a specific response from other individuals (Newcombe and Hartman 1973; Quinn and Tolson 1986; Rouger and Liley 1993; Cardwell et al. 1996, Meyer and Liley 1982). Even though compounds like Estradiol-17B in guppies *Poecilia reticulata* (Johansen 1985) and steroids or prostaglandins in herring *Clupea harengus* (Sherwood et al. 1991) are linked to the cause of a specific reaction, little is known of the specific mechanism for production or reception of chemical cues. Most experiments have only confirmed that a chemical produced from one individual elicits a specific response from another of the same species (Liley and Stacey 1983). Regardless, the fact that fish release a chemical that can attract others of the same species is the foundation for this study to determine if brook trout can be attracted and captured using these means.

OBJECTIVES

1. Determine what type of combination of mature brook trout seeded into hoop nets can capture the most brook trout.

2. Identify movement patterns of brook trout tagged with fluorescent elastomer tags recaptured in hoop nets.

3. Compare the number of hours spent to remove brook trout using hoop nets to other methods.

METHODS

The study area for this project was East Threemile Creek (ETC), which is a small stream in northeastern Idaho near the town of Spencer. The study area included the upper 6.2 km of stream above a weir. The stream averaged 1.7 m in width and 0.11 m in depth. Elevation ranged from 1,944 m at the weir to 2,323 m at the upper end of watered stream. Brook trout were the only fish species present.

During the summer of 2004, abundance estimates were performed on 12 sites in ETC for all trout present with multiple-pass electrofishing using backpack electroshockers. The furthest downstream site was chosen randomly with the remaining sites chosen systematically every 500 m measured upstream to the end of fish-bearing stream. Electrofishing sites ranged from 43-75 m in length. Each electrofishing section was closed with block nets to meet the assumption of a closed population. After each pass, all fish were measured to the nearest mm (total length) and weighed using a Pesola scale to the nearest gram. Maximum-likelihood abundance estimates were calculated for each sample section using the MicroFish software program (Van Deventer and Platts 1989). Abundance estimates were calculated separately for fish ≥100 mm and fish <100 mm (total length, TL) because capture efficiencies are not equal (Reynolds 1996).

Fish >80 mm were tagged using fluorescent elastomer tags (FET, Northwest Marine Technology) in different combinations of body location and color to identify the marking site and allow identification of movement of tagged fish. Fish held at each site in live wells indicated that mark retention was 100% at all but one site (70%) after 24 h. Literature with the tagging equipment stated that if the tag was retained for 24 h it would be permanent (Northwest Marine Technology).

In the fall of 2004, ETC was blocked at the lower end of the study section with a two-way weir to assess fish movement and to prevent immigration into the study section from below the weir that could not be sampled due to large beaver dam complexes. The study employed a randomized block design. The five treatments included the following mature brook trout combinations: 1) a single mature male, 2) three mature males, 3) a mature male/female pair, 4) a single mature female, and 5) no fish. The experimental unit was an individual hoop net and the response variable was the number of fish captured in a net over a 24 h period. Five treatments were grouped together as a set, and two sets (10 nets) represented a block. There were eight blocks ordered in an upstream fashion to account for unknown variation in capture due to fish densities, stream size, or other environmental factors that could not be controlled. Treatments were randomly assigned to nets within a set. The number of brook trout captured was summed for each net for analysis.

Net capture data were analyzed using a 2-way analysis of variance to test differences in mean captures by treatment. The two factors used in the model were block and treatment. Capture data were transformed using $\ln(x + 1)$ to normalize the data. Separate analyses were run for mature males, mature females, and immature fish. All statistical analysis was conducted using SAS software (SAS Institute).

Hoop trap nets measuring 38 cm in diameter and 1.8 m long with 1.6 m wings were placed in stream locations in ETC according to the sampling design. Nets were fixed in the stream channel using rebar. Wings were tied up out of the water so they would not block the entire stream.

Brook trout used as treatments were captured by electrofishing from ETC below the weir. Mature male and female brook trout were identified by distinguishing morphology differences between the sexes as well as light massage to feel for mature gonads. Treatment fish were placed in 460 mm perforated polyvinyl chloride tubes enclosed on both ends with soft, half-inch mesh netting. Tubes containing fish were placed in the cod end of hoop nets. Extra treatment fish were held in live wells below the weir. Treatment fish in tubes were replaced with fish captured in the nets when possible; otherwise, they were replaced with fish from the live wells. Treatment fish were replaced when signs of morbidity were noticed and overall, fish were replaced in each net on average every seven days. Sex was positively identified through dissection after fish were removed as treatments.

Nets were installed on September 15, 2004 and removed on October 20, 2004. Treatments were placed in the nets on September 16. All nets were checked once daily during the entire sampling period (35 d). All brook trout were removed from the traps as they were checked, overdosed with anesthetic, and frozen.

Brook trout were thawed in the lab and measured (nearest mm, TL), weighed (nearest g), sexed, and checked for tags. Fish were designated as mature male, mature female, or immature. Males were considered mature if gonads were large and milky white, and immature if gonads were small and threadlike. Females were considered mature when ovaries contained large, well-developed eggs, and immature if ovaries were thin and granular with no developed eggs. Fluorescent elastomer tags were detected using a blue light and amber glasses to enhance the tags.

In order to compare the relative cost of this project to other brook trout removal projects, associated time and costs expended were accounted for. Total hours expended, travel expenses, and equipment costs were calculated to get a rate of person hours/1 km treated and the number of fish captured per person/hour expended for removal.

RESULTS

Brook trout were the only fish species captured in ETC in 2004. We estimated an abundance of 2,020 ± 410 brook trout ≥100 mm and 1,950 ± 697 brook trout <100 mm. Of the estimated 3,970 brook trout present, 1,360 (34%) were captured with hoop nets (777 ≥100 mm and 583 <100 mm). We captured 658 sexually mature brook trout with nearly five times more males (544) than females (114). Nets seeded with the male/female pair caught the most mature brook trout (235) followed by nets with no fish (166, Table 3). The single male captured the fewest fish (64). More males than females were captured for all treatments. The differences in means of ln(X+1) transformed counts between mature males and females were significant because none of the 95% confidence intervals overlapped (Figure 10). Comparing the difference for males between treatments, nets seeded with a female captured almost double the number of brook trout, on average, than those seeded with males (Figure 10). Raw means are included in Figure 10 to illustrate that the male/female pair treatment captured approximately double the number of males as all other treatments. In the first 20 days of trapping, 86% of the total number of brook trout were captured (Figure 11). Few fish were captured in the last 15 d, and total daily catches were below 10 fish/d for the final 10 d.

Effects of blocks and treatments were significant. The blocking variable was significant for males, females, and immature brook trout and explained 24%, 24%, and 42%, respectively, of the variation in the models. Treatments differed in the number of mature male brook trout ($P = 0.0025$) and immature fish ($P = 0.043$) but not mature females ($P = 0.29$) captured in hoop nets. A posteriori Tukey's honestly difference significance tests between treatments for mature males shows that the male/female pair and single female treatments captured significantly more fish than the single male, but no other comparisons between treatments were significant for males. The number of immature brook trout captured did not differ between any of the treatments.

Only 24 of the 237 brook trout tagged with the FET were recaptured, and movement of brook trout in ETC was variable but was generally upstream in direction. There did not appear to be any pattern in distance moved compared to timing of recapture.

Overall, 479 person hours were spent conducting the field project in the fall of 2004. This translates to 76 person hours/1 km spent removing brook trout.

DISCUSSION

The use of mature brook trout as attractants for their own removal may have promise. Although only 34% of the estimated population in ETC was removed, the major objective of this project was to determine if one treatment was responsible for capturing more brook trout than another, not to maximize removal.

The male/female pair treatment caught the most brook trout overall. This was unexpected and contrasts with the findings of Young et al. (2003) who captured significantly more mature brook trout in nets seeded with males. However, no female/male treatment was used, and their study did not run nets through the entire brook trout spawning period. This may have affected captures if there were 1) increased attraction by having both sexes together, or 2) changes in the responsiveness of brook trout as the spawning season progressed.

Another unexpected finding was that the treatment net with no seeded fish captured the second highest number of brook trout. It was envisioned as a "control," but in reality, it could not be, because once a fish entered the net it then became a treatment. It represented what would be captured at random if empty nets were placed in the stream but should not be considered a true control. The fact that two out of the 16 nets with no seeded fish were responsible for 32% of the total fish captured for that treatment suggests the no fish treatment may have been the beneficiary of a net location effect. It is unclear why those two particular nets caught so many fish, but their positions may have caught fish no matter what the treatment. In one case in block three, one net caught 45 fish, while another net with the same treatment set approximately 30 m upstream caught only two.

The amount of variation in capture between nets with the same treatment was problematic for all treatments. Examining the difference between least square means of mature males and females between treatments suggests that males may be more attracted to nets with females or possibly repulsed by nets with males. The nets seeded with females captured approximately twice as many mature males as those seeded with males (Figure 10). The average number of male brook trout captured with the male/female pair treatment without transformation was 12.3 fish/net. The average number of male brook trout captured with the single female, none, three males, and single male treatments were 8.0, 7.6, 4.5, and 2.7 fish/net, respectively (Figure 10). The male/female treatment captured more fish/net, on average, than the other four treatments, even though the statistical analysis did not provide conclusive evidence to support that conclusion. Because the design of this study was to test the difference between treatments, nets were set in one position and not moved during the study period whether or not they captured fish. This is most likely the reason for the variation in catch. In further projects of this nature, attempts should be made to design a study that reduces the variation in net captures, such as moving nets if they fail to catch fish for a certain amount of time.

Hoop netting captured five times more mature male brook trout (544) than mature females (114). This concurs with Young et al. (2003), who captured ten times more mature males than females. All male brook trout ≥100 mm were mature, and 49% of the females captured ≥100 mm were mature. Therefore, if we assume the sex ratio of the population was approximately 50:50 (McFadden et al. 1961; Cooper et al. 1962; Wydoski and Cooper 1966), then we removed 54% of the estimated 1,010 mature male brook trout ≥100 mm but only 23% of the estimated 495 mature females ≥100 mm. This suggests that hoop nets did capture a higher proportion of males than females assuming the 50:50 sex ratio, but probably only twice as many. Unfortunately, the actual sex ratio is unavailable.

Brook trout in ETC generally were recaptured in the same area they were marked, with a greater proportion captured upstream of the marking location. The fact that most fish were recaptured upstream of their marking location was not surprising (Gowan and Fausch 1996, Adams et al. 2000). What was surprising was how few marked fish were recaptured. Likely, fish moving downstream were not exposed to capture by the downstream facing nets unless they moved upstream again at some point, introducing bias (Gowan et al. 1994). This would explain why 86% of the brook trout in ETC were captured in the first 20 d of sampling; as water temperatures decreased, brook trout were moving downstream and not vulnerable to capture (Figure 11).

Considerably less time was spent removing brook trout using hoop nets than comparable electrofishing studies, ranging from 25% (Thompson and Rahel 1996) to 95% (Kulp and Moore 2000) less person hours/1 km of stream treated. Granted, only 34% of the brook trout were removed in ETC, but as was stated before, this study was designed to test treatments, not maximize removal. It remains undecided if hoop netting can be as or more efficient at removing brook trout compared to other commonly used techniques.

RECOMMENDATIONS

1. Use an alternate sampling design to test hoop nets seeded with different combinations of adult brook trout to alleviate problems with location and variation in catches encountered in this study.

ACKNOWLEDGMENTS

We would like to thank Joe Kozfkay, Art Butts, John Cassinelli, Andy Pristavok, Mike Vaughn, Matt Grover, Dane Oldham, Dan Garren, and Trapper Bradshaw for assisting in hoop net installation, removal, and data collection during the field study. Steve Elle and Sara Nelson also assisted with working up fish in the lab. Claire McGrath, Alan Byrne, and Rob Ryan provided comments and suggestions that greatly improved the manuscript. This project was funded by the Bonneville Power Administration.

LITERATURE CITED

Adams, S. B., C. A. Frissell, and B. E. Rieman. 2000. Movements of nonnative brook trout in relation to stream channel slope. Transactions of the American Fisheries Society 129:623-638.

Bettoli, P. W., and M. J. Maceina. 1996. Sampling with toxicants. Pages 303-333 in B. R. Murphy and D. W. Willis editors. Fisheries Techniques. American Fisheries Society. Bethesda, Maryland.

Cardwell, J. R., P. W. Sorensen, G. J. Van Der Kraak, and N. R. Liley. 1996. Effect of dominance status on sex hormone levels in laboratory and wild-spawning male trout. General and Comparative Endocrinology 101:333-341.

Cooper, E. L., J. A. Boccardy, and J. K. Anderson. 1962. Growth rate of brook trout at different population densities in a small infertile stream. The Progressive Fish Culturist 24:74-80.

Dunham, J. B., S. B. Adams, R. E. Schroeter, and D. C. Novinger. 2002. Alien invasions of aquatic ecosystems: Toward an understanding of brook trout invasions and potential impacts on inland cutthroat trout in western North America. Reviews in Fish Biology and Fisheries 12:373-391.

Ehrlich, P. R. 1989. Attributes of invaders and the invading process: vertebrates. Pages 315-328 in J. A. Drake, H. A. Mooney, H. A. DiCastri, et al. editors. Biological Invasion: a Global Perspective. Wiley & Sons. New York, New York.

Finlayson, B., and 11 coauthors. 2005. Native inland trout restoration on national forests in the Western United States: time for improvement? Fisheries 30(5):10-19.

Fausch, K. D. 1989. Do gradient and temperature affect fist distribution of and interactions between juvenile brook char and other salmonids in streams? Physiology and Ecology Japan, Special Volume 1:303-322.

Gowan, C., M. K. Young, K. D. Fausch, and S. C. Riley. 1994. Restricted movement in resident stream salmonids: a paradigm lost? Canadian Journal of Fisheries and Aquatic Sciences 51:2626-2637.

Gowan, C., and K. D. Fausch. 1996. Mobile brook trout in two high elevation Colorado streams: re-evaluating the concept of restricted movement. Canadian Journal of Fisheries and Aquatic Sciences 53:1370-1381.

Gresswell, R. E. 1991. Use of antimycin for removal of brook trout from a tributary of Yellowstone Lake. North American Journal of Fisheries Management 11:83-90.

Griffith, J. S. 1972. Comparative behavior and habitat utilization of brook trout (*Salvelinus fontinalis*) and cutthroat trout (*Salmo clarkii*) in small streams in Northern Idaho. Journal of the Fisheries Research Board of Canada 29:265-273.

Johansen, P. H. 1985. Female pheromone and the behaviour of male guppies (*Poecilia reticulata*) in a temperature gradient. Canadian Journal of Zoology 63:1211-1213.

Kulp, M. A., and S. E. Moore. 2000. Multiple electrofishing removals as a management tool for restoration of southern Appalachian brook trout, Great Smoky Mountains National Park. North American Journal of Fisheries Management 20:259-266.

Liley, N. R., and N. E. Stacey. 1983. Hormones, pheromones and reproductive behaviour in fish. Pages 1-63 *in* W. S. Hoar, D. J. Randall, and E. M. Donaldson. Fish physiology. Volume 9B. Academic Press. New York, New York.

McFadden, J. T. 1961. A population study of the brook trout, *Salvelinus fontinalis.* Wildlife Monograph 7. 73 pp.

Meyer, J. H., and N. R. Liley. 1982. The control of production of a sexual pheromone in the female guppy *Poecilia reticulata*. Canadian Journal of Zoology 60:1505-1510.

Moyle, H. A. 1986. Fish introductions into North America: patterns and ecological impact. Pages 27-43 in H. A. Mooney and J. A. Drake, editors. Ecology of Biological Invasions of North America and Hawaii. Springer-Verlag. New York, New York.

Newcombe, C., and G. Hartman. 1973. Some chemical signals in the spawning behavior of rainbow trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada 30:995-997.

Quinn, T. P., and G. M. Tolson. 1986. Evidence of chemically mediated population recognition in coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Zoology 64:84-87.

Reynolds, J. B. 1996. Electrofishing. Pages 221-253 in L. A. Nielson and D. J. Johnson editors. Fisheries Techniques. American Fisheries Society. Bethesda, Maryland.

Rouger, Y., and N. R. Liley. 1993. Effect of social environment on plasma hormones and availability of milt in spawning male rainbow trout (*Oncorhynchus mykiss* Walbaum). Canadian Journal of Zoology 71:280-285.

Sakai, A. K., F. W. Allendorf, J. S. Holt, and 12 others. 2001. The population biology of invasive species. Annual Review of Ecological Systems 32:305-332.

SAS Institute. 2004. The SAS system for windows, version 9.1. SAS Institute, Cary, North Carolina.

Shepard, B. B., R. Spoon, and L. Nelson. 2002. A native westslope cutthroat trout population responds positively after brook trout removal and habitat restoration. Intermountain Journal of Science 8:191-211.

Sherwood, N. M., A. L. Kyle, H. Kreiberg, C. M. Warby, T. H. Magnus, J. Carolsfeld, and W. S. Price. 1991. Partial characterization of a spawning pheromone in the herring *Clupea harengus pallasi*. Canadian Journal of Zoology 69:91-103.

Snyder, D. E. 2003. Electrofishing and its harmful effects on fish. Information and technology report USGS/BRD/itr 2003-002: U.S. Government Printing Office, Denver, Colorado.

Thompson, P. D., and F. J. Rahel. 1996. Evaluation of depletion-removal electrofishing of brook trout in small Rocky Mountain streams. North American Journal of Fisheries Management 16:332-339.

Thurow, R. F., D. C. Lee, and B. E. Rieman. 1997. Distribution and status of seven native salmonids in the interior Columbia River Basin and portions of the Klamath River and Great Basins. North American Journal of Fisheries Management 17:1094-1110.

Van Deventer, J., and W. Platts. 1989. A computer software system for entering, managing, and analyzing fish capture data from streams. Research Note INT-352. USDA Forest Service, Intermountain Research Station. Ogden, Utah.

Wydoski, R. S., and E. L. Cooper. 1966. Maturation and fecundity of brook trout from infertile streams. Journal of the Fisheries Research Board of Canada 23(5):623-649.

Young, M. K., B. K. Micek, and M. Rathbun. 2003. Probable pheromonal attraction of sexually mature brook trout to mature male conspecifics. North American Journal of Fisheries Management 23:276-282.

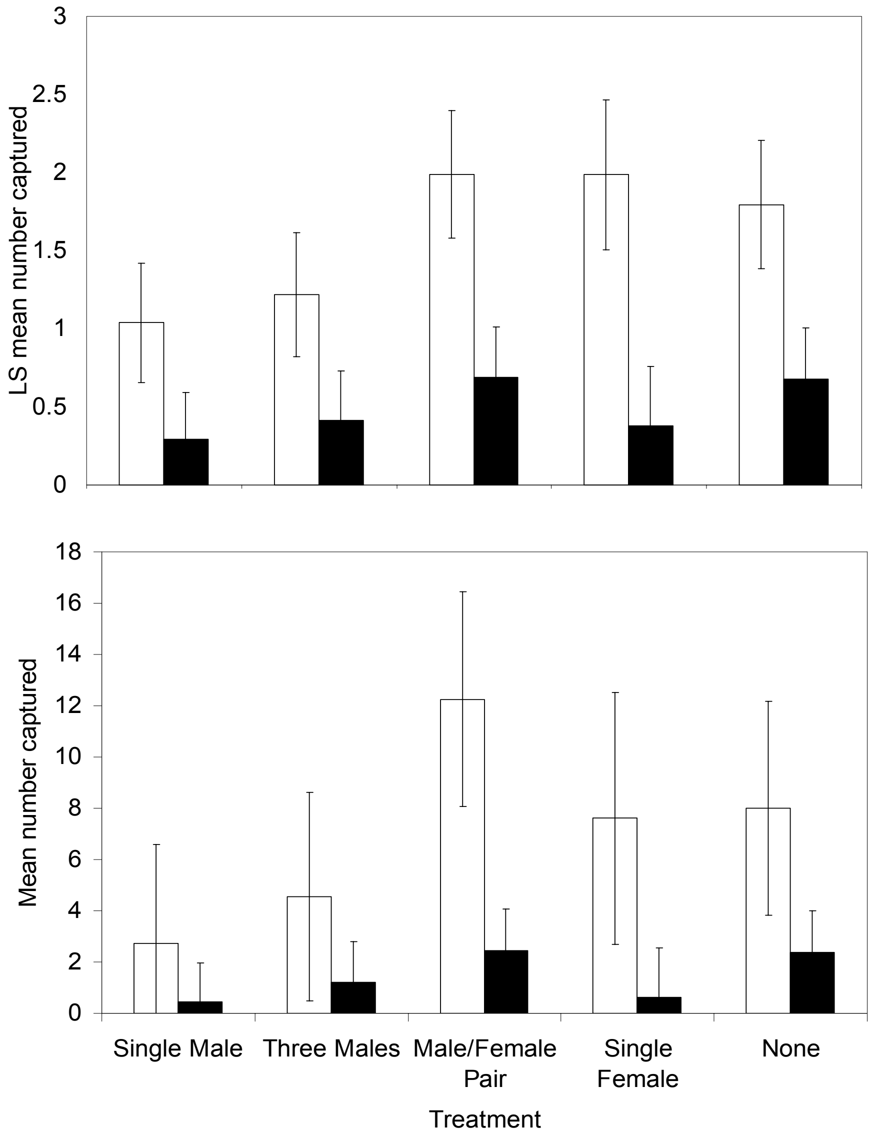

Figure 10. Mean number of mature male (open bars) and female (solid bars) brook trout captured in hoop nets seeded with five treatments in East Threemile Creek, Idaho. The top panel is for the least square (LS) means of ln (x+1) transformed counts calculated from ANOVA. The bottom panel is the raw means without transformation provided to illustrate the magnitude of difference between treatments. Error bars are 95% confidence intervals.

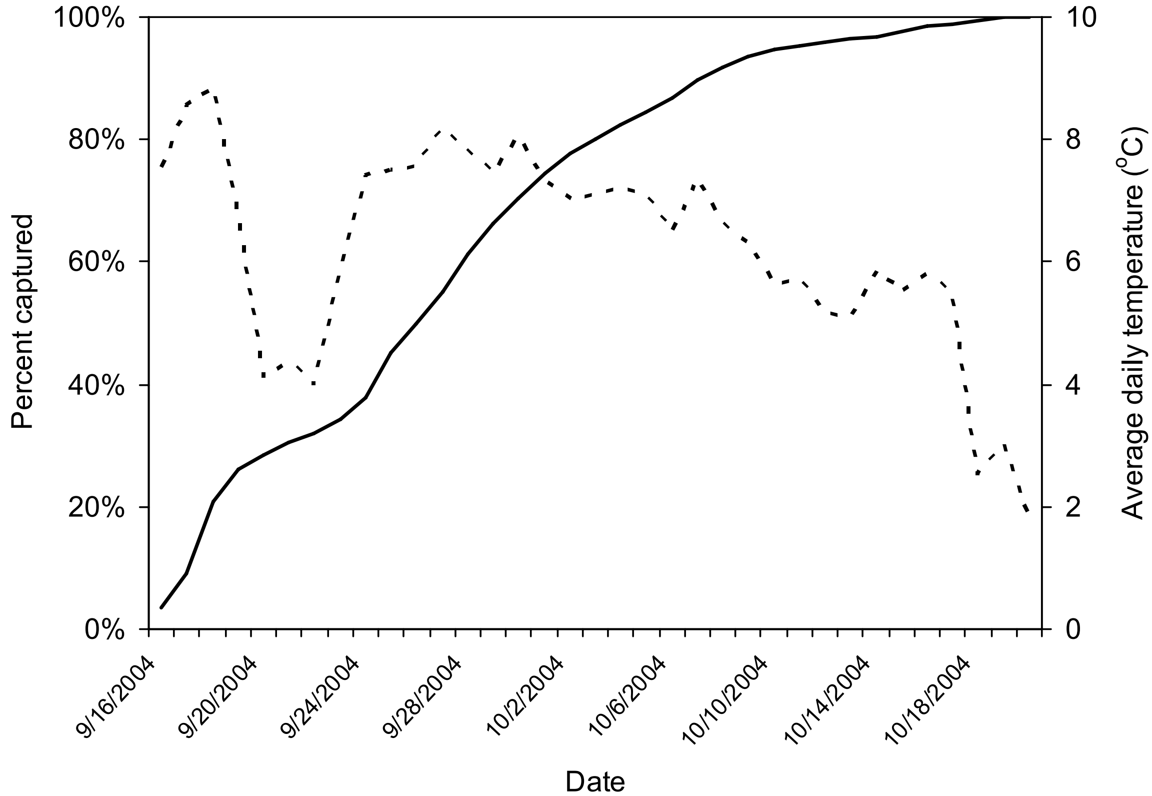

Figure 11. Cumulative catch of total brook trout captured in hoop nets (solid line) and mean daily water temperatures (dotted line) in East Threemile Creek, Idaho.

Table 3. The total number of mature brook trout captured in hoop nets for each treatment tested in each block (two nets) in East Threemile Creek, Idaho.

	Block								
Treatment	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Male/Female Pair	37	29	65	7	71	13	9	4	235
None	23	19	47	42	10	3	10	12	166
Three Males	31	13	2	31	3	2	14	1	97
Single Male	16	1	16	6	5	9	11	0	64
Single Female	NA*	13	27	23	15	10	6	2	96
								Total	658

*NA – not available, single female treatment not tested in block 1.

Prepared by:	**Approved by:**
	IDAHO DEPARTMENT OF FISH AND GAME
Kevin A. Meyer Principal Fisheries Research Biologist	Virgil K. Moore, Chief Bureau of Fisheries
James A. Lamansky, Jr. Senior Fisheries Technician	Daniel J. Schill Fishery Research Manager